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Summary Report

Analysis/Design and Prototype Construction of a Selected Mobility and Restraint Device

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SUMMARY REPORT

FINAL ANALYSIS/DESIGN AND PROTOTYPE CONSTRUCTION OF A SELECTED MOBILITY AND RESTRAINT DEVICE

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FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS 9-9336, "Final Analysis/Design and Prototype Construction of a Selected Mobility and Restraint Device," for the Manned Spacecraft Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Spacecraft Integration Office of the Manned Spacecraft Center with Mr. Maynard C. Dalton acting as the Technical Monitor. This report summarizes the effort performed during the period of this contract.

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I. INTRODUCTION

Since the duration of space flights will be lengthened in the near future, additional spacecraft volume will be required to accommodate the equipment needed to support such a mission. The larger volume spacecraft will require a mobility and restraint device to aid the crewman in performing his zero-gravity tasks and experiments. This mobility and restraint device must be designed to offer the crewman as much or as little restraint as deemed necessary. In addition to being simple and compact, the device should provide a simple interface with the user.

The mobility and restraint device developed, designed, fabricated, and tested at the Martin Marietta Corporation during this contract offers all the above advantages. The device is known as the "shuffler" and is a shoe that slips on as primary footwear. Permanent magnets are embedded in the ball and heel areas of the sole and sized to meet attractive force requirements.

Magnetic attraction has been used previously as a mobility device, but its use has been more or less confined to an earth-oriented gate. The shuffling technique, as the name implies, deviates significantly from previous concepts. Here, both feet remain in continuous contact with the ferrous surface to assure continuous stability. A low coefficient of friction material is placed in the ball area of the foot and a high coefficient of friction material is placed in the heel and toe areas. The shuffling movement is facilitated by the permanent magnet in the ball area of the foot. The magnet has sufficient strength to maintain contact, but is not strong enough to impede the sliding motion required for this mode of transportation. The pushing force for shuffling originates from the heel area of the foot.

The shufflers can greatly assist in equipment monitoring and making adjustments. The wearer can operate essentially in an earth-like condition. Once the shufflers are in place, they may function in a similar manner to floor-mounted restraints or "Dutch Shoes"; body twisting, bending, and stretching are readily accomodated. If adjustment must be made outside of the man's reach while in a fixed position, simple short shuffling movements can easily reposition the body.

Another major use of the shufflers could be in transporting bulky or high inertia equipment. In cases when only the individual is involved, a free-fly or swimming mode can be used. The shoes are so conceived as to facilitate easy separation from the floor for this mode.

II. STUDY SCOPE AND OBJECTIVE

The objective of this contract was to provide the final analysis, detailed design drawings, and final design documentation for mobility and restraint footwear known as "shufflers." Once the design of the shuffler became final, two pairs of prototype footwear were fabricated for testing in neutral buoyancy tanks and parabolic aircraft flights where a zero-gravity environment can be approached. The intended end use of the shuffler is to make astronauts more stable while transporting objects and performing other necessary maintenance tasks in space.

The concept required the use of embedded permanent magnets. Since a ferrous surface is required in conjunction with the permanent magnets, the study also required the analysis and documentation of the lightest weight floor consistent with the required holding forces for the various proposed crew tasks.

In achieving the objectives, the scope of the study included examination of holding forces involved during performance of crew tasks; performing a magnetic analysis to ensure that the required forces could be obtained; determination of the permanent magnet specifications and the floor specifications; construction and testing of engineering evaluation models; comparison of test results with analytical results; material study; and preparation of detailed design drawings.

III. RELATIONSHIP TO OTHER NASA EFFORTS

The mobility and restraint footwear developed and designed during this contract could prove to be the solution to NASA's mobility and restraint problems for future large volume space stations. This concept provides the future space crew with a mobility and restraint aid for use in zero gravity as they perform their required tasks. The concept is a very simple one. The footwear worn by the crewmen leave his hands free. There are no adjustments to be made and no bulky equipment that imposes a limitation on the degree of travel. The footwear is so conceived that once restraint is no longer needed, separation from the floor is easily accomplished. In addition, this concept provides the user with as much or as little restraint as he deems necessary. In other words, upon finishing a task in one work area, he could move to another area without having to remove himself from the restraint device.

Assuming that this is an acceptable concept for restraint, other types of restraint design such as toe holds, hand rails, etc, could be greatly reduced on future space stations. The floor design in the required restraint areas would be affected.

IV. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

Immediately following contract go-ahead, a detailed study plan was submitted to provide an outline for the final analysis, design, documentation, and prototype fabrication of the mobility and restraint footwear (shuffler). The study approach consisted of analysis, fabrication of several engineering evaluation models, evaluation testing, and preparation of engineering drawings and the floor specification.

An investigation was started to determine the activities with which an astronaut could be involved when using shufflers. The motions analyzed and assumptions for each are listed below:

1) Shuffling - An astronaut could shuffle at an average pace of 1 ft/sec;

2) Passing a package - An astronaut will pass a standard package with a maximum mass of 150 lb from shoulder level;

3) Receiving a package - An astronaut will receive a standard package with a maximum mass of 150 lb no lower than his center of gravity;

4) Body reposition - An astronaut could take two steps and rotate his body 90 deg in 2 sec;

5) Body rotation - An astronaut could rotate his body 90 deg in 2 sec while his feet are stationary. (The moment of inertia associated with such a movement would be half the value of the one used if his entire body rotated);

6) Tugging on a package - No assumptions;

7) Operating an instrument panel - No assumptions.

Assumptions used in the analysis of the above motions were based on similar movements performed in a one-gravity environment. The results of the zero-gravity simulation tests indicate that the assumptions made were correct and the shuffler concept was workable and practical.

V. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

A force analysis and a magnetic analysis were used to analyze the shuffler. The force analysis was prepared on motion by an astronaut in a zero-gravity environment as various tasks were performed using the shufflers. Both static and dynamic conditions were analyzed as the astronaut pushed, passed, or tugged equipment. A summary of the results of the force analysis is shown in the following tabulation. It shows the maximum attractive force required per shuffler to be 13.6 lb when passing a package. It should be stressed that these forces are the minimum required for stability.

Task	Maximum Reactive Horizontal Force Required (lb)	Maximum Attractive Force Required (lb)
Shuffling	1.71	6.0
Passing Package	2.62	13.6
Receiving Package	3.97	13.6
Body Reposition	3.91	5.4
Body Rotation	1.77	2.4
Operation of Instrument Panel	2.5	12.7

The magnetic analysis produced the design of a magnetic circuit that would produce the forces necessary to perform the above activities. An Indox V permanent magnet assembly was chosen for use in the shufflers because of its physical size and large pull characteristics. These assemblies are commercially available from Bunting Magnetics in Chicago and will be used in conjunction with a 30-mil smooth ferrous surface. The distributed attractive force will be approximately 8 lb in the ball area of the shuffler and 15 lb in the heel area. This introduces an ample safety factor and gives the user increased stability as shown in the final report. A supplementary floor specification has been produced in addition to the final report for a more detailed introduction to floor design.

Several engineering evaluation models were constructed and tested by design engineers in simulated zero gravity. Neutral buoyancy tanks in Denver and the six-degree-of-freedom simulator MSFC in Huntsville were used. The results confirmed the analytical work and showed the shuffler to be a workable concept. The tests also acquainted the design engineers with configuration design requirements that were incorporated in the final design. They are as follows:

1) The shuffler sole must be flexible to permit correct orientation of the magnet assemblies;

2) The magnet assembly in the ball area of the foot must float or remain flexible within the shuffler to allow constant contact while shuffling;

3) A closed toe cap is necessary to permit lifting in the toe area of the foot while shuffling;

4) A restraint strap is necessary to lift the heel magnet from the ferrous surface;

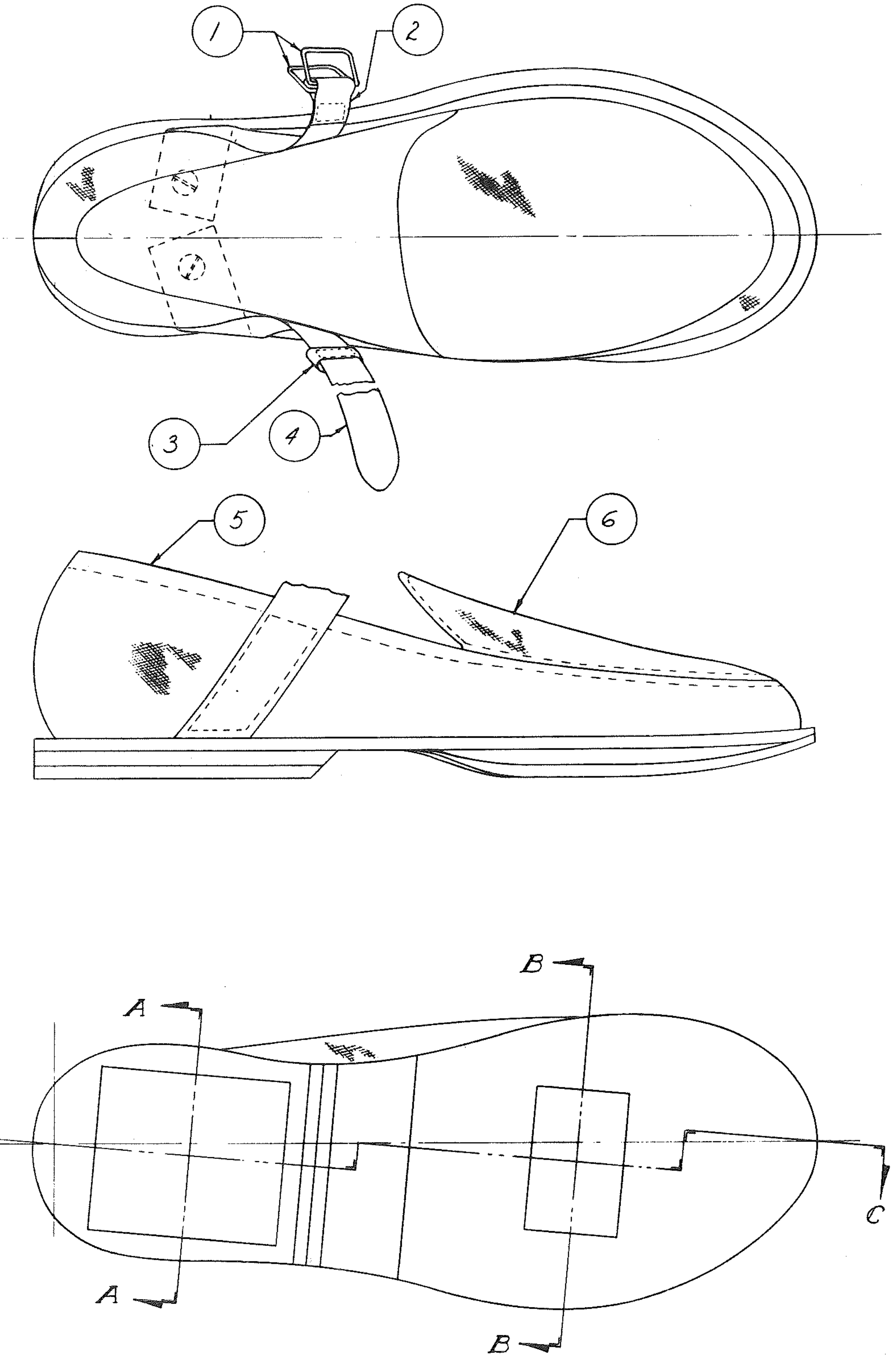
5) Because of wear the Teflon surface covering the magnet in the ball area of the foot must be replaceable;

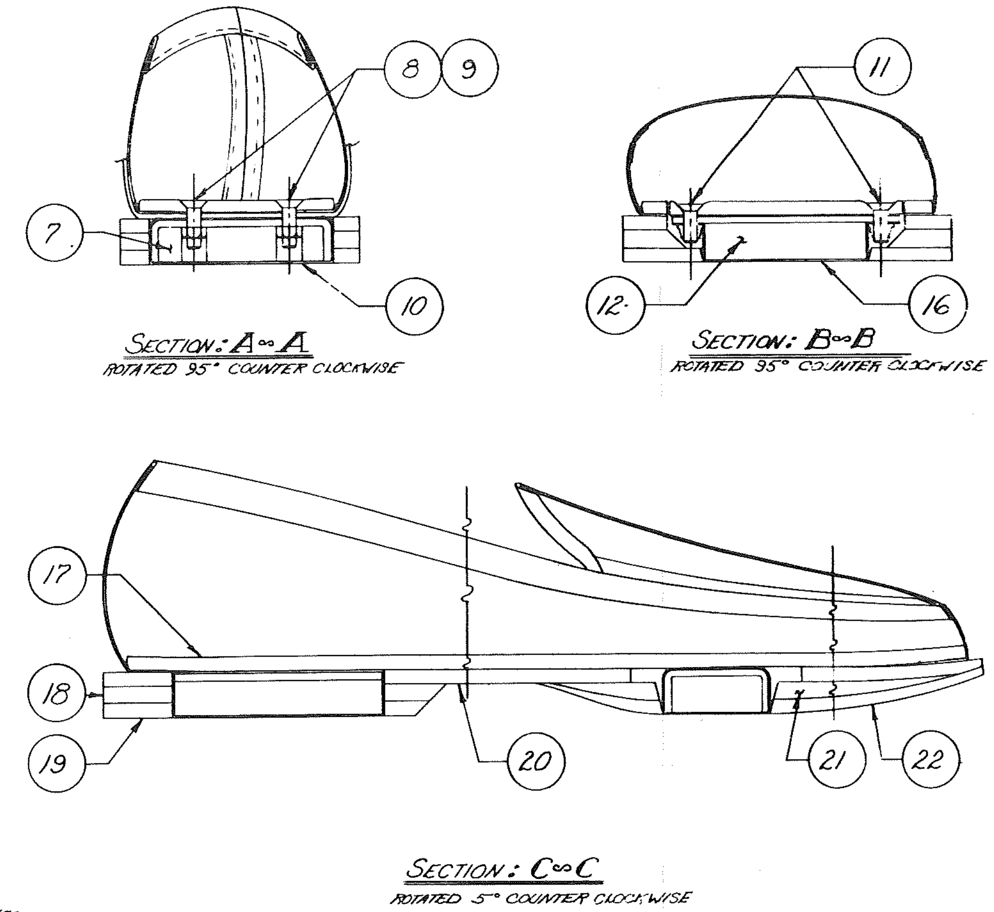
6) D-ring fasteners are preferred over buckles, snaps, or velcro for use on the restraint straps.

There is a wear problem associated with the teflon covering of the front magnet assembly. This introduces the maintenance problem of replacing the worn teflon surfaces. We investigated other methods of applying a low coefficient of friction surface to the magnet assembly but because of the limitation on time and cost, the teflon covering was retained.

Films showing the testing of shufflers at a neutral buoyancy tank in Denver and the six-degree-of-freedom simulator in Huntsville are available from Maynard Dalton, Technical Monitor at MSC, Houston, or Arthur Rosener, Program Manager at Martin Marietta Corporation, Denver.

Two final prototype shufflers were constructed, incorporating the results of the analysis and testing. They are compatible with spacecraft environment and neutral buoyancy test tank waters, and are designed as primary footwear with a nominal size of 9D. Detailed design drawings (Fig. 1) have been made of the final shuffler design and are incorporated into the final report of the study (MCR-69-507).





NOTES:

1) LEFT SHOE SHOWN - RIGHT SHOE OPPOSITE

1 2) POINTS A, B, C, D, E, & F ARE MATCH POINTS BETWEEN ITEMS 5, 6, & 17 AS SHOWN

2 3) ITEMS 23 & 24 ARE NOT CALLED OUT ON FACE OF DRAWING
ITEM 24 IS USED ON ITEMS 2, 3, 4, 5, & 6 ONLY
ITEM 23 IS USED ON ITEMS 2, 3, 4, 5, 6, 7, 10, 17, 18, 19, 20, 21, & 22.

4) ASSEMBLY PROCEDURE
a) SEW ITEMS 5 & 6 TOGETHER & ROLL & SEW FREE EDGES WITH NOMEX THREAD (ITEM 24).
b) ATTACH ITEMS 1 TO ITEM 2 & SEW IN PLACE WITH ITEM 24.
c) SEW ITEM 4 TO ITEM 3 WITH NOMEX THREAD (ITEM 24).
d) USE EPOXY (ITEM 23) ON FREE ENDS OF ITEMS 2, 3, & 4 TO PREVENT UNRAVELING.
e) BOND ASSEMBLED TOP (ITEMS 5 & 6) TO INSOLE (ITEM 17) WITH EPOXY (ITEM 23).
f) ATTACH ITEMS 1, 2, 3, 4, 7, 8, 9, 10, 11, 12 & 16 TO INSOLE (ITEM 17).
g) BOND ITEMS 18 & 21 TO SOLE (ITEM 20) WITH EPOXY (ITEM 23) & GRIND TO CONFIGURATION SHOWN.
h) BOND ITEMS 19 & 22 TO ASSEMBLED ITEMS 18, 20, & 21 WITH EPOXY (ITEM 23) & GRIND TO CONFIGURATION SHOWN.
i) BOND ASSEMBLED ITEMS 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 16 & 17 TO ASSEMBLED ITEMS 18, 19, 20, 21, & 22 WITH EPOXY (ITEM 23).
j) SEW STRAPS (ITEMS 2 & 4) TO SIDES OF SHOE (ITEM 5) AS SHOWN WITH NOMEX THREAD (ITEM 24)
k) SMOOTH ALL ROUGH EDGES & MAKE SURE MAGNETS EASILY ATTAIN COMPLETE CONTACT WITH A FLAT FERROUS SURFACE.

ITEM	QTY	SIZE	DESCRIPTION	MAT'L
24	100 YDS	—	THREAD	NOMEX
23	3	TUBE KITS	3M FLEXIBLE EPOXY	[illegible]
22	2	3/16"x6 1/2x4 3/4	SOLE BUILD-UP	FLUOREL [illegible]
21	2	1/4"x6 1/2"x4 3/4"	SOLE BUILD-UP (FOAM)	FLUOREL [illegible]
20	2	3/16"x12"x4 3/4"	SOLE	FLUOREL 1059
19	2	3/16"x4 3/4"x3 1/2"	HEEL BUILD-UP	FLUOREL 1059
18	2	1/4"x4 3/4"x3 1/2"	HEEL BUILD-UP (FOAM)	FLUOREL [illegible]
17	2	3/16"x11 1/2"x4 1/4"	INSOLE	FLUOREL [illegible]
16	2	.010"x5"x3 3/4"	MAGNET COVERING	TFE TEFLON
15	8	MS20426AD3-5	RIVIT, SOLID, CSK	2117-T4 AL AL
14	4	NAS1068C3	NUT, SELFLOCKING, PLATE	CRES
13	2	BM4982	MAGNET-BUNTING MAGNETICS CO.	INDOX V ASSY
12	2	—	SUB ASSY MADE FROM ITEM 13, 14, 15	—
11	4	AN510-10R6	10-32x3/8"LG FLAT HEAD SCREW	CRES
10	2	1/16"x4 1/4"x6"	MAGNET COVERING - DUPONT VITON	#249-196-1
9	4	AN315C3R	10-32 HEX NUT	CRES
8	4	AN510-10R8	10-32x1/2"LG FLAT HEAD SCREW	CRES
7	2	BM4974	MAGNET - BUNTING MAGNETICS CO.	INDOX V ASSY
6	2	7"x8"	CLOTH - SHOE TOP	PBI CLOTH
5	2	9"x27"	CLOTH - SHOE SIDES	PBI CLOTH
4	2	1"Wx15"LG	STRAP	PBI WEBBING 101
3	2	1"Wx3 3/4"LG	STRAP	PBI WEBBING 101
2	2	1"Wx6 1/2"LG	STRAP	PBI WEBBING 101
1	4	1"	"D" RINGS	CRES

MATERIAL REQ'D FOR ONE PAIR OF SHOES

S.C. HARRIS 0445 10/1/64

Fig. 1 Mobility and Restraint Footwear Design Configuration

FOLDOUT FRAME A

FOLDOUT FRAME B-

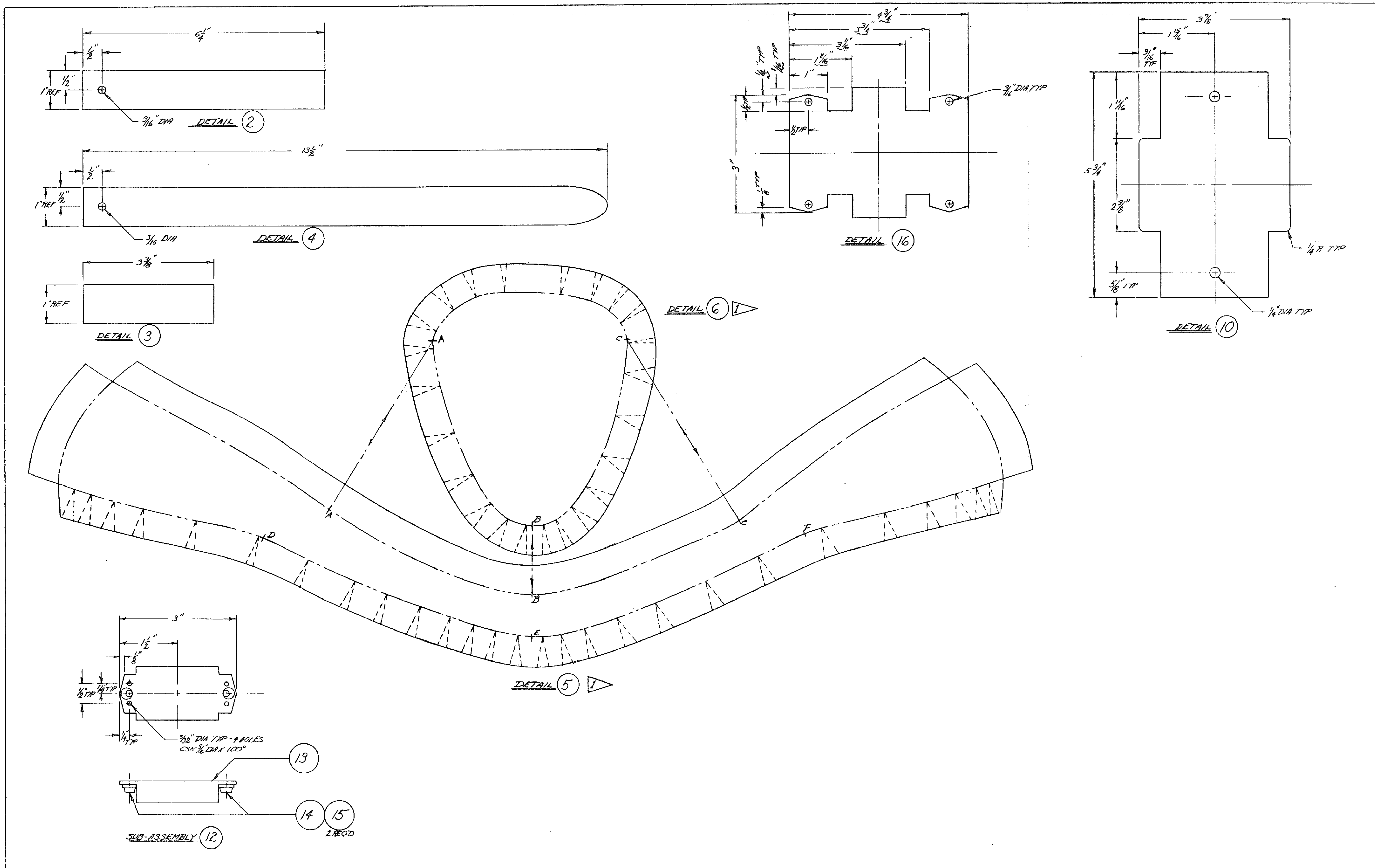


Fig. 1 (cont)

FOLDOUT FRAME A

FOLDOUT FRAME B

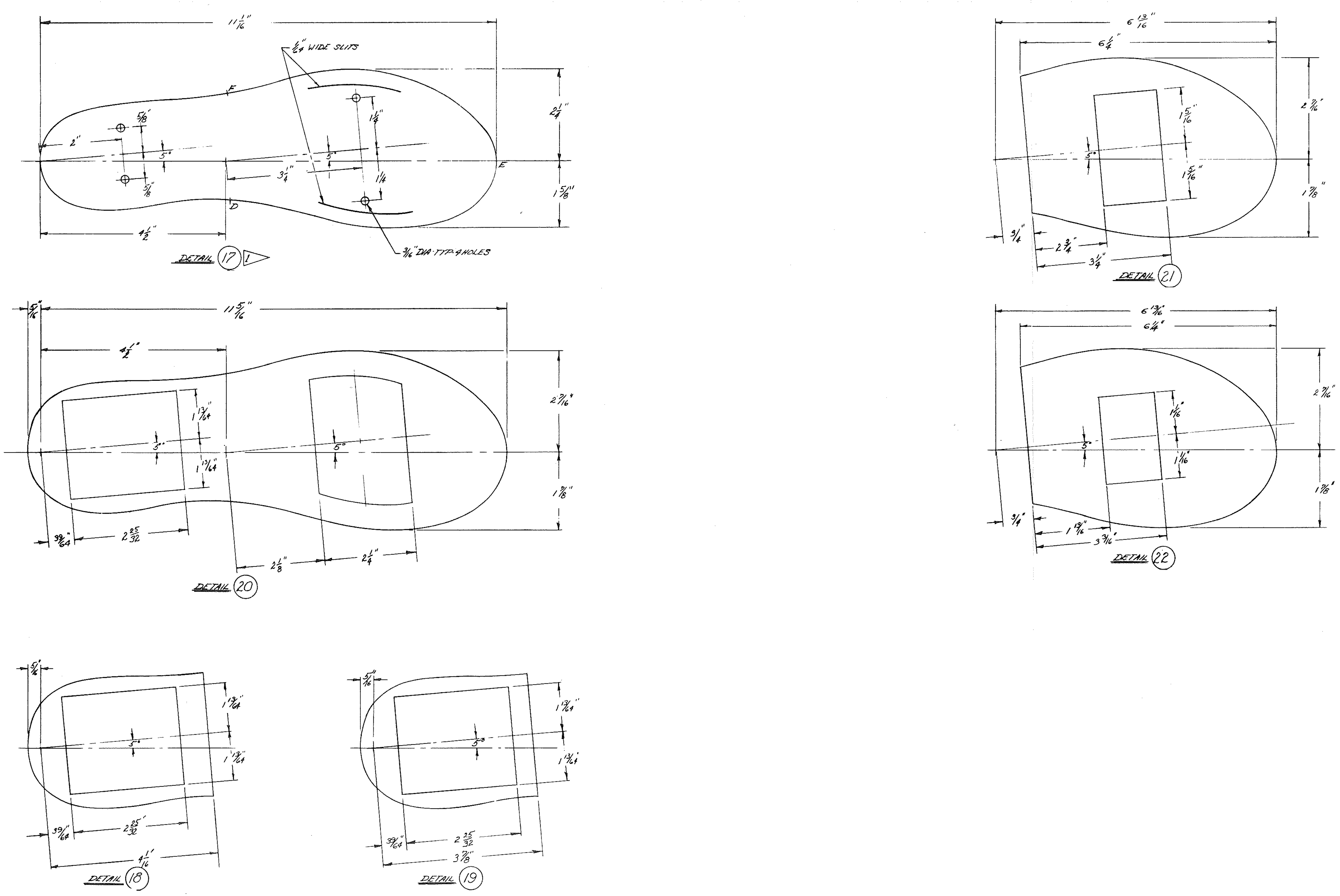

1/64" WIDE SLITS
3/16" DIA TYP 4 HOLES
DETAIL 17
DETAIL 20
DETAIL 18
DETAIL 19
DETAIL 21
DETAIL 22

Fig. 1 (concl)

The final written report presents the results of our study together with specific recommendations concerning the use of the shufflers, supporting data, calculations and other information necessary to substantiate this study. The drawings and final report are deliverable items under this contract.

VI. STUDY LIMITATIONS

There were certain study limitations in the area of design itself and the testing that follows. The final configuration of the mobility and restraint footwear was limited in the area of analysis, testing, and the evaluation models produced. Seven motions were considered as related to crewmen's work tasks and activities in a large workshop area. The maximum forces and torques assumed with these motions are shown in the following tabulation.

Task	Design Resistance
Shuffling	1.71 lb
Passing Package	2.62 lb
Receiving Package	3.97 lb
Tugging	6.50 lb
Operating Instrument Panel	
Pushbutton	2.5 lb
Rotary Selector	6.0 in.-lb
Lower Body Reposition	3.91 lb
Upper Body Reposition	1.77 lb

It is entirely conceivable that a crew member could easily surpass these resistances. The values were derived from reasonable assumptions in a one-gravity environment and various applicable documents.

The testing results were very informative and exceeded all expectations. However, the results were limited by the simulated zero gravity in neutral buoyancy test tanks and the six-degree-of-greedom zero-gravity simulator. The duplication of the exact analytical movements was difficult and could only be accomplished in a true zero-gravity environment.

The evaluation models produced were different from the final shuffler model, but they did play an important part in the design of the final prototype. The final design has not been tested in simulated zero gravity, but should give better results than any of the evaluation models.

VII. CONCLUSIONS AND RECOMMENDATIONS FOR RESEARCH

The wear problem associated with the teflon covering on the front magnet assembly indicates that further work in this area should be accomplished. We have investigated armalon covering, teflon spray, and potting the permanent magnet assembly in Teflon. The armalon covering was quickly worn through during testing and was rejected because teflon had better wear characteristics. Teflon spray was rejected because we could not obtain as durable a coating as desired. Potting the magnet assembly in teflon introduced another problem. Because of the curing process involved with such an operation, the magnet assembly would have to be remagnetized. We feel that with development, the most promising solution would be the teflon spray.

It should be noted that the shufflers fabricated during this contract have been designed as primary footwear. In actual flight usage, the shufflers should be designed as secondary footwear. If this were the case, a simple donning and doffing operation could take place, eliminating the need of exchanging two pair of primary footwear.

The use of magnetic attraction in space introduces an interesting problem of weight design. Magnets and the materials that they attract are usually made from a rather dense ferrous material. An effort could be made to reduce the weight of the magnetic circuit and make the use of magnetism more practical for spacecraft environment. The introduction of ceramic assemblies has brought about a high attractive force and low weight characteristic, but magnetic circuit design can still be improved. A study of high permeability materials, permanent magnet design, and magnetic circuit configuration should be considered for further research. This could produce thinner floors and lighter shufflers, thus providing a greater potential weight savings when trading off between other types of restraint devices.

VIII. SUGGESTED ADDITIONAL EFFORT

The results of this contractual study indicate that further testing of the shufflers in a zero-gravity condition is warranted. This testing should be accomplished first on parabolic flights of the KC-135 aircraft. If the concept continues to look promising, a shuffler package should be incorporated as an experiment on an early Apollo Applications Program flight. The shufflers could be used in conjunction with existing scheduled experiments.

The analysis has indicated that a 0.030-in. pure iron floor will be required for use with the shufflers in their area of operation. For the zero-gravity parabolic aircraft flights, an 18x156x0.030-in. iron sheet could be secured to the ceiling of the aircraft cabin. This iron sheet would weigh approximately 23.2 lb and should have structural support. If incorporated on an early Apollo Applications flight, it would be very impractical to completely cover the existing grid-type floor design of the Orbital Workshop with a large piece of sheet metal. Therefore it would be desirable to use smaller pieces that can be easily stored or fastened in particular operational areas. Various combinations of 2x3-ft plate, 0.030 in. thick, could be used to provide a ferrous surface that could be used while performing existing planned experiments. Experiments could be performed with and without the shufflers.

We recommend that six separate pieces of the above dimension floor be incorporated into an experiment package for use in the workshop. This would enable an astronaut to have two 3x4-ft work areas connected by a 6-ft walkway. Also, by aligning the floor pieces in a straight line, an astronaut could exercise the shuffling mode over a distance of 18 ft.

The workshop floor will consist of structural members sandwiched between two grid networks. The grid network will be 4 in. thick and will have a uniform grid pattern throughout the floor area. This uniform pattern will allow the metal sheets to be used in nearly any orientation desired.

Since the flat sheets must remain fairly flexible as far as location is concerned, they need not be attached permanently. The grid-type floor could be attached in several ways. Some possibilities are magnets, spring clips, or clamps. They must leave the metal sheet relatively free from discontinuities on its surface, however, so the astronaut could move about without stumbling.

In addition to testing, a detailed examination of each AAP experiment could be made to determine various usages. A detailed weight tradeoff of the shufflers versus other types of restraints could be performed.